IS 15382-4 (2003): Insulation Coordination for Equipment within Low-Voltage Systems, Part 4: Considerations of High-Frequency Voltage Stress [ETD 19: High Voltage Engineering]

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IEC 60664-4 (1997)
(Superseding SP 39 : 1987)

भारतीय मानक

निम्न-वोल्टता तंत्र में उपस्करों का विद्युतरोधी समन्वयन

भाग 4 उच्च-आवृति वोल्टेज दाब को ध्यान में रखते हुए

Indian Standard

INSULATION COORDINATION FOR EQUIPMENT WITHIN LOW-VOLTAGE SYSTEMS

PART 4 CONSIDERATIONS OF HIGH-FREQUENCY VOLTAGE STRESS

ICS 29.080.30

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

September 2003

Price Group 10

High Voltage Engineering Sectional Committee, ET 19

NATIONAL FOREWORD

This Indian Standard (Part 4) which is identical with IEC 60664-4 (1997) 'Insulation coordination for equipment within low-voltage systems — Part 4 : Considerations of high-frequency voltage stress' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendations of the High Voltage Engineering Sectional Committee and approval of the Electrotechnical Division Council.

This standard was first published in 1987 as SP 39 'Special publication — Guide for insulation coordination within low voltage systems'. The revision of this special publication was felt with a view to align our standard with international practices.

This standard consists of the following parts under the general title 'Insulation coordination for equipment within low voltage systems':

Part 1	Principles, requirements and tests
Part 2	Application guide, Section 1 Dimensioning procedure worksheets and dimensioning examples
Part 3	Use of coatings to achieve insulation coordination of printed board assemblies
Part 4	Consideration of high frequency voltage stress

This standard is to be read in conjuction with Part 1 of this standard.

The text of the IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

With the publication of this standard SP 39 shall be withdrawn.

Only the English text of the International Standard has been retained while adopting it as an Indian Standard.

CROSS REFERENCES

In this adopted standard, references appear to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Indian Standard*	*Degree of Equivalence*
IEC 60112 (1979) Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions	IS 2824 : 1975 Method for determining the comparative tracking index of solid insulating materials under moist conditions (*first revision*)	Technically equivalent
IEC 60664-1 (2002) Insulation coordination for equipment within low voltage systems — Part 1: Principles, requirements and tests	IS 15382 (Part 1) : 2003/IEC 60664-1 (2002) Insulation coordination for equipment within low-voltage systems: Part 1 Principles, requirements and tests	Identical

(*Continued on third cover*)

IS 15382 (Part 4) : 2003
IEC 60664-4 (1997)

Indian Standard

INSULATION COORDINATION FOR EQUIPMENT WITHIN LOW-VOLTAGE SYSTEMS

PART 4 CONSIDERATIONS OF HIGH-FREQUENCY VOLTAGE STRESS

1 Scope

This report deals with insulation subjected to high-frequency voltage stress within low-voltage equipment. Steady-state voltages with frequencies up to 100 MHz are considered.

NOTE – High-frequency stress due to transient voltages is not considered.

2 Reference documents

IEC 60112:1979, *Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions*

IEC 60664-1:1992, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

3 Clearances

Breakdown of clearances usually occurs in less than one submicrosecond. With respect to that time scale, an a.c. voltage of power frequency has an essentially constant amplitude. For instance at 50 Hz, the amplitude remains within 99 % of its peak value for 1 ms. Therefore, during the development leading to breakdown, the peak value of the voltage is effective. This normally results in identical a.c. (peak) and d.c. breakdown voltages.

At much higher frequencies, a reduction of the voltage from its peak value and even polarity reversal have to be taken into account during the development of breakdown. This effect will result in an increase of the breakdown voltage.

Up to now, the effect of the ions (which are usually positive) which are generated during inception of breakdown has not been considered. These ions are generated at the crest of the sine-wave and there is usually enough time for them to travel to the electrodes during the remaining part of that halfwave. However, in large clearances or at high frequency, the polarity may be reversed before the ions have been extracted from the clearance. This will result in a distortion of the electrostatic field and will reduce the breakdown voltage. The average velocity of the ions is approximately 6×10^2 m/s [1]*. At 50 Hz, the time interval between the crest and the zero crossing of the sine-wave is 5 ms, resulting in the ions moving approximately 300 cm. Therefore, at power frequency, this aspect will only be relevant for very large clearances. However, if the frequency is increased to the kHz range, this phenomenon will also be relevant for small clearances.

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* The figures in square brackets refer to annex A (Bibliography)

The superposition of both effects results in typical curves which exhibit a minimum breakdown voltage for a certain frequency. For clearances with homogeneous and approximately homogeneous field distribution, data is shown in figures 1 and 2 [2]. At 25 MHz, the breakdown voltage is nearly the same as at 50 Hz. Figure 2 shows that the clearance is a very important parameter with respect to this behaviour.

With respect to the frequencies presently used, the range with the initial decrease of breakdown voltage with increasing frequency is of greater interest. This frequency range, being up to several MHz, is described in more detail hereafter.

For small clearances in N_2 at atmospheric pressure, which has similar breakdown characteristics as air, the reduction of the breakdown voltage may only be 10 %, as shown in figure 3 [3]. However, for frequencies exceeding 1 MHz, the reduction also becomes effective for very small clearances less than 0,5 mm. For larger clearances there is a greater reduction in the breakdown voltage, as shown in figure 4 [4].

As a conclusion, for homogeneous and approximately homogeneous conditions, the maximum reduction of the breakdown voltage with frequency is about 20 %. The critical frequency at which the reduction of the breakdown voltage occurs is approximately:

$$f_{\text{crit}} \approx 0{,}7/d$$

where

f_{crit} is the critical frequency at which the reduction of the breakdown voltage occurs, in megahertz;

d is the clearance in millimetres.

The insulating characteristics of homogeneous and approximately homogeneous clearances in air at atmospheric pressure with respect to frequency can be summarized by the following statements.

- Above f_{crit}, the breakdown voltage becomes lower with increasing frequency. The reduction in breakdown voltage may be up to 20 %.
- The breakdown voltage has its minimum at frequencies between 1 MHz and 5 MHz. With higher frequencies, the breakdown voltage becomes higher and may exceed the value at power frequency.

For inhomogeneous field conditions, f_{crit} is still obtained approximately from the equation given. Above f_{crit}, the influence of frequency on the breakdown voltage is much more significant. This can be seen from figure 5 [5] for comparatively large clearances and a 30° point electrode in combination with a plane electrode of 15 cm diameter. The reduction of the breakdown voltage with respect to that at 50 Hz can be more than 50 %. The results are strongly influenced by the electrode configuration. The lowest breakdown voltages were measured with the plane electrode earthed. As a general rule, it is essential to have approximately homogeneous field conditions if there is high-frequency voltage stress.

4 Creepage distances

In IEC 60664-1, tracking is the only phenomenon taken into account for dimensioning of creepage distances. However, recent research [6] provides evidence that this does only apply for very severe environmental conditions, and if the materials used are not resistant to tracking (see IEC 60112). Under more favourable environmental conditions, tracking does not seem to be relevant for dimensioning. In this case, the flashover voltage across the surface of the insulating material is reduced by pollution and has to be taken into account for dimensioning [7].

It is not known whether tracking is influenced by the frequency of the voltage. However, under conditions of severe pollution, or for materials having a low comparative tracking index, small dimensions are not possible, and a safety margin has to be provided. This safety margin may also allow for a possible influence of frequency on the withstand capability.

For less pollution, the flashover voltage across the surface of the insulation seems to be relevant for dimensioning and a possible influence of frequency has to be considered. However, this influence may already be covered by the frequency dependence of the breakdown voltage of the associated clearance according to clause 3.

Long-term influence of humidity is likely to change this situation. A significant reduction of the breakdown voltage across insulation surfaces, especially for higher frequencies, occurs under such conditions. This is mainly a problem caused by water absorption within solid insulation, and this phenomenon is considered in clause 5.

5 Solid insulation

Two failure mechanisms of solid insulation are normally relevant. One failure mechanism results from dielectric loss at high electric stress. Increased heating will occur, which may lead to thermal instability and thermal breakdown. This usually takes place within a few minutes and can be easily verified. Additionally, solid insulation can include gas gaps or voids, either caused by different layers of insulation, interfaces between insulating parts and conductive parts, or by imperfect manufacturing of the insulation material. In such small gaps, partial discharges are likely to cause eventual failure of solid insulation even if the dielectric stress is sufficiently low so as not to cause thermal breakdown.

For solid insulation, the frequency of the voltage is a very important influencing factor. The dielectric loss for a given frequency is obtained from the following equation:

$$P_v = \tan \delta \times 2 \pi f \times U^2 \times C$$

where

P_v is the power dissipation;

$\tan \delta$ is the loss factor;

f is the frequency;

U is the voltage across the solid insulation;

C is the capacitance of the insulation arrangement.

Due to the dependence of the loss factor tan δ on frequency, the influence of frequency on the dielectric loss may be lower or higher than can be expected from the apparent linear dependency. This results in a higher probability of thermal breakdown and a reduction of the short-time dielectric withstand capability. This phenomenon has been investigated on different insulating materials [8]. The most important results are shown in figure 6. For a frequency of 1 MHz, the short-time breakdown field strength may only be 10 % of the power frequency value. The breakdown field strength does not seem to reach a lower limit even at frequencies as high as 100 MHz.

The dielectric strength of solid insulation in general, and especially at high-frequency voltage, is further reduced by the influence of humidity and temperature.

The influence of long-time storage on the breakdown field strength of solid insulation at high-frequency voltage under high humidity is shown in figure 7 [9]. The reduction of the breakdown field strength of mica-filled phenolic is extraordinarily high. This is a significant problem at power frequency, but is further aggravated with increasing frequency. The poor performance of mica-filled phenolic is caused by its comparatively high water absorption, which was found to be in the order of 1 % by weight under such conditions. Under the same conditions, the water absorption of glass-silicone laminate was only 0,3 % by weight.

The breakdown field strength of solid insulation is a function of the thickness of the material, and very thin films may have a breakdown field strength one order of magnitude higher than that of the 0,75 mm test specimen. This is shown in figure 8 [10]. With increasing frequency, there is a significant reduction of the values. At 1 MHz only approximately 10 % of the 50 Hz values were found. At such high frequencies, the behaviour of thin films seems to be similar to that of specimens having approximately 1 mm thickness. The influence of the thickness of the film on the breakdown voltage can be seen in more detail in figure 9 [10]. There is some indication that the breakdown voltage of very thin films is slightly less affected by frequency, but even for 0,01 mm film, there is still a significant reduction.

Figure 10 [11] shows that the breakdown field strength of solid insulation at all frequencies is additionally reduced with increasing temperature. The influence of increased temperature on the breakdown voltage of thin films is shown in figure 11 [10], which shows that the reduction of breakdown voltage with increasing temperature is aggravated with increasing frequency.

So far, only short-time stress and thermal breakdown have been considered. For long-time stress, partial discharges have also to be taken into account [12]. Experience shows that, in particular, thin insulation used in low-voltage equipment cannot withstand these discharges for long periods. Therefore, partial discharges should not be maintained under steady-state conditions. Partial discharges are to be expected at a dielectric stress significantly lower than that causing thermal breakdown.

Detailed results concerning the partial discharge characteristics at high-frequency voltage are only available for frequencies up to a few kHz [13, 14]. In that range, it has been established that the time to failure caused by partial discharges is inversely proportional to frequency. This relationship has been used for accelerated testing. Therefore, especially at higher frequencies, a reasonable lifetime cannot be expected when partial discharges occur.

Detailed measurements have been made on coated printed circuit boards. One of the test boards is shown in figure 12. A typical plot of the partial discharge intensity (apparent charge q) is shown in figure 13 [15].

For this type of test specimen, an increase of the apparent charge with increasing frequency is more likely to occur than a decrease. It has been established that at high frequency, the time to failure may only be in the order of minutes. Therefore, partial discharge testing at high frequency for such periods may be destructive.

Additionally, the partial discharge inception voltage U_i and the partial discharge extinction voltage U_e may be influenced by frequency. As shown in figure 14 [15], some reduction of the partial discharge voltages with increasing frequency is to be expected for coated printed circuit boards. However, this characteristic seems to depend on the type of test specimen. As shown in figure 15 [15], the partial discharge voltages of optocouplers do not seem to be influenced by frequency. At high frequency, there seems to be even some tendency of a decrease of the apparent charge q. However, the combined effect of frequency and apparent charge as the source of failure is more onerous than at power frequency.

6 High-frequency testing

The following tests are relevant with regard to frequency:

- verification of the short-time dielectric strength for clearances and, in particular, for solid insulation by an a.c. voltage test at high frequency;
- with regard to long-time electric stress, verification that no partial discharges are maintained under steady-state conditions.

At the present time, high-frequency test equipment is only available with limited power output, so that only components and small subassemblies can be tested.

6.1 High-frequency breakdown test

This test is similar to the high-voltage test at power frequency. At present, no standard high-power HF test voltage sources are available.

6.1.1 Test method

It has been observed that the high-frequency withstand is influenced by equipment temperature and environmental conditions. The test should be performed under the most onerous conditions that may be encountered in service, including the temperature rise caused by normal operation of the equipment.

6.1.2 Test equipment

For frequencies up to a few MHz, one way to generate the test voltage is by using a high-power oscillator in combination with an air-core transformer. An appropriate circuit is shown in figure 16 [10]. With this circuit, fixed frequencies from 100 kHz up to 10 MHz can be adjusted with an output power of 1,5 kW. Due to the high capacitive loading, both frequency and output voltage are influenced by the test specimen.

In order to cover the whole frequency range from a few kHz to 1 MHz, a test circuit consisting of a high-power amplifier and an HF resonance transformer can be used. The circuit is shown in figure 17 [15], together with a partial discharge detection circuit. The frequency range for resonance transformers dependent on the number of secondary turns is shown in figure 18. High-frequency operation requires a low number of secondary turns. In order to cover the whole frequency range, several resonance transformers are required.

6.2 High-frequency partial discharge test

6.2.1 Test method

Due to the high risk of deterioration of the test specimen at high frequencies, the rate of voltage rise should be as high as possible without causing overshoot. In general, the noise level during high frequency partial discharge testing will be significantly higher than that occurring during power-frequency testing.

The preliminary results obtained for optocouplers give some indication that the partial discharge voltages are not significantly influenced by frequency. If this could be verified on a more representative basis, a partial discharge test with power-frequency voltage could be sufficient to give enough information about the partial discharge characteristics of optocouplers at high frequency. For coated printed circuit boards, this is different, because both the partial discharge voltages and the partial discharge intensity are influenced by frequency. These aspects need further investigation with other test specimens.

6.2.2 Test equipment

The measurement of partial discharges is more difficult, because both the test voltage source and the partial discharge measuring equipment are not readily available.

However, this difficulty may be overcome by employing laboratory apparatus as shown in figure 17. The partial discharge detection is performed by digital integration with a digital storage oscilloscope of high sampling rate. With this test circuit, the data shown in figures 13 to 15 were obtained.

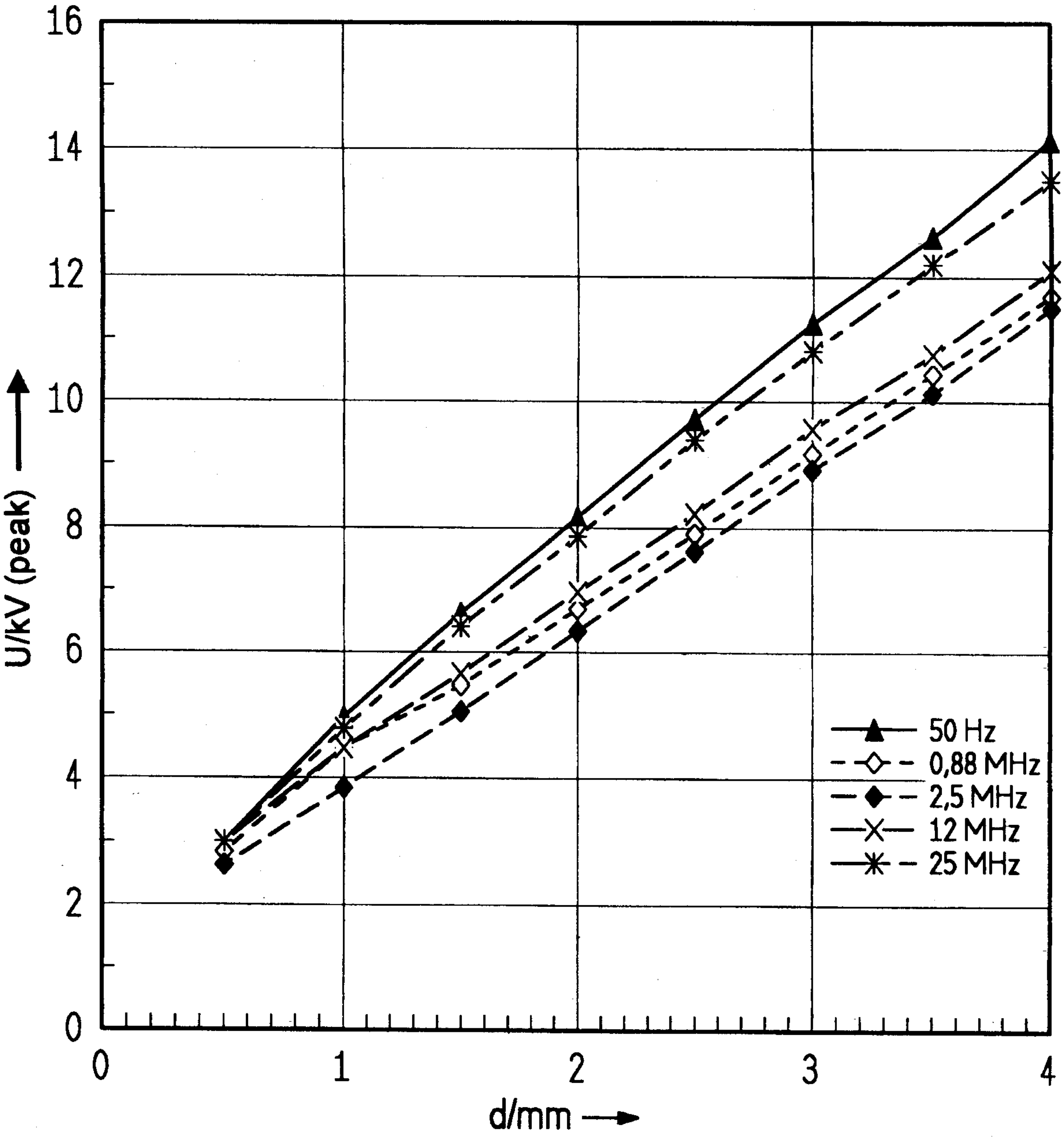


Figure 1 – Breakdown at high frequency in air, homogeneous field [2]

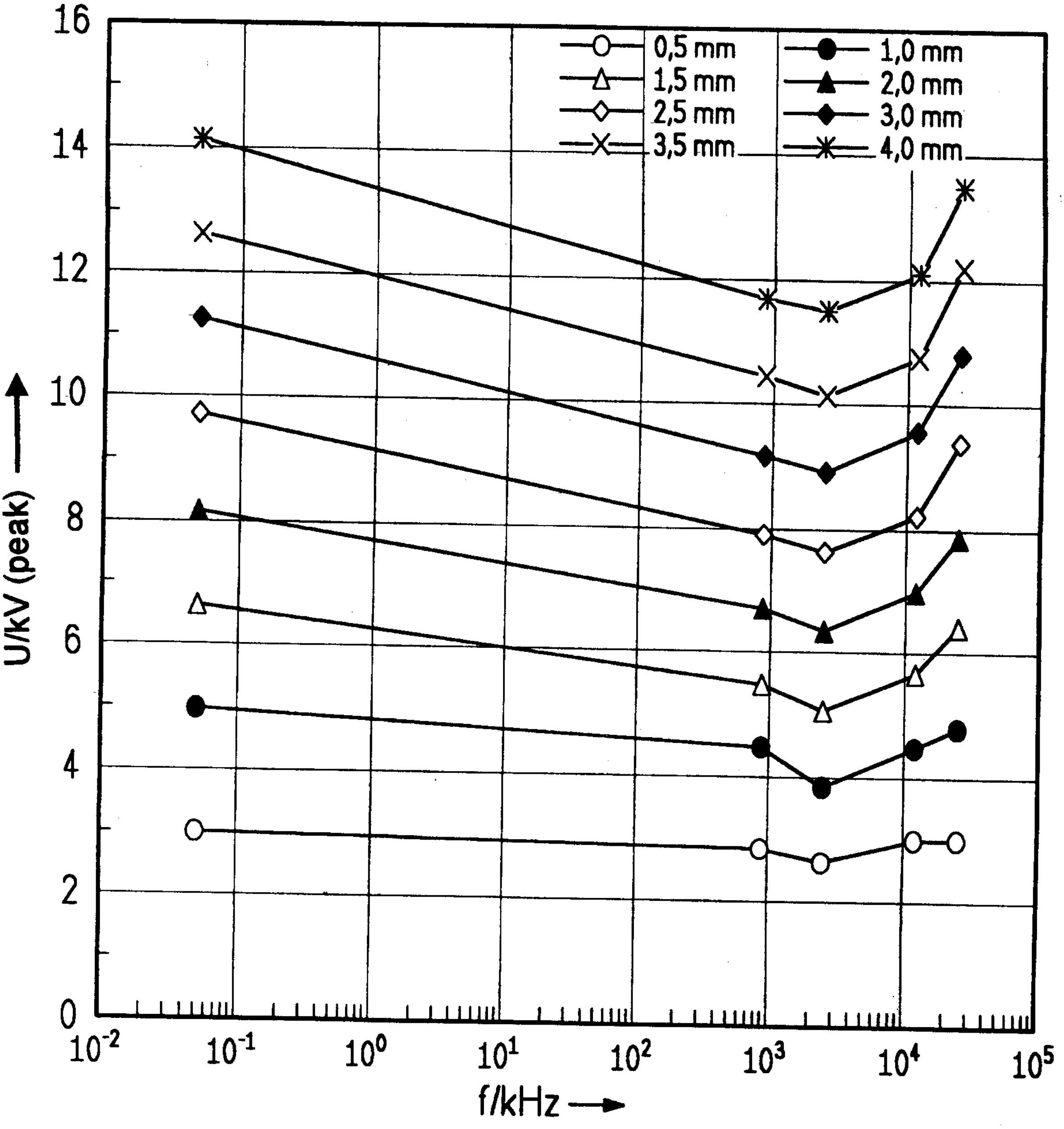


Figure 2 – Breakdown at high frequency in air, homogeneous field [2]

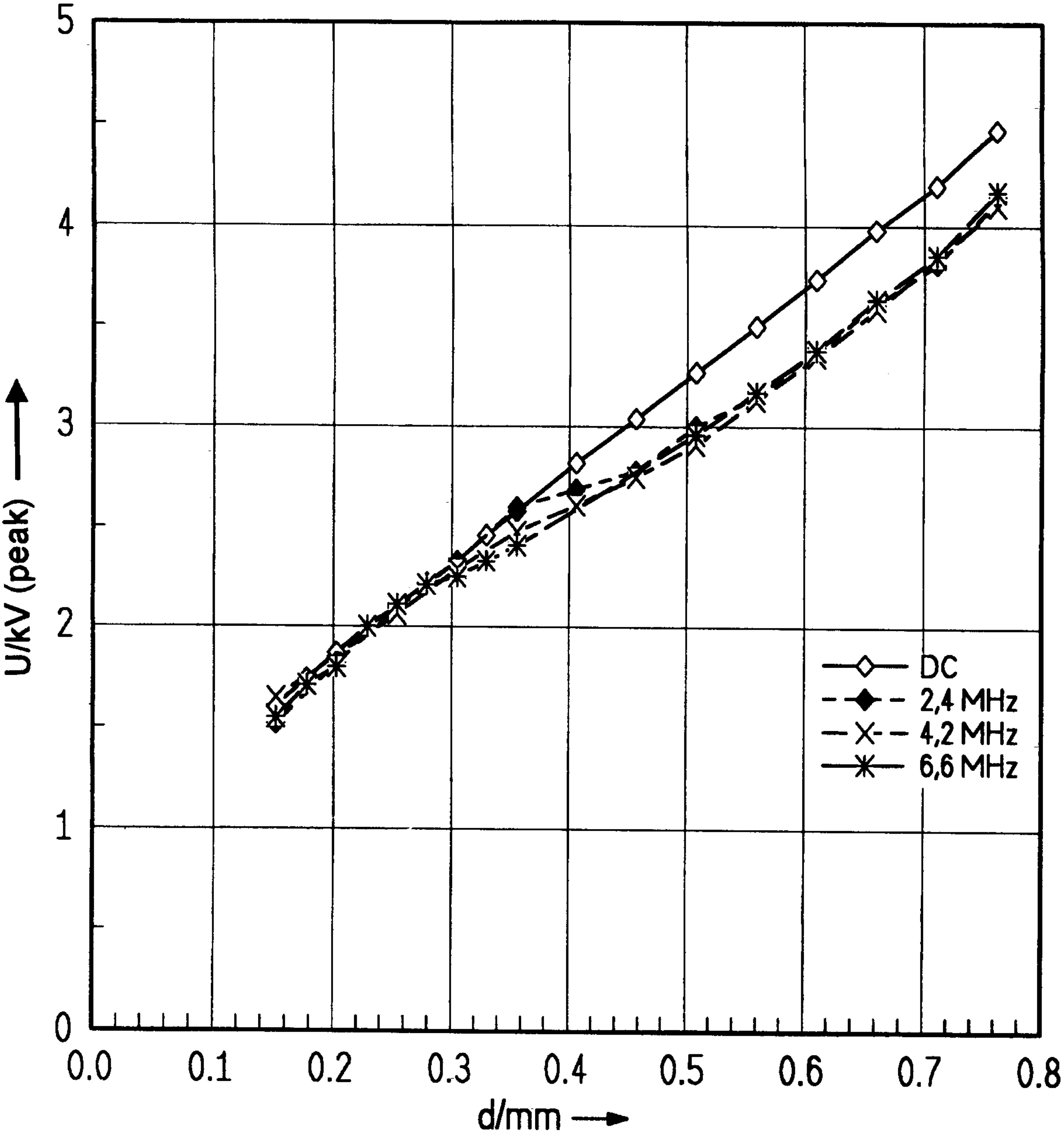


Figure 3 – Breakdown at high frequency in nitrogen, homogeneous field [3]

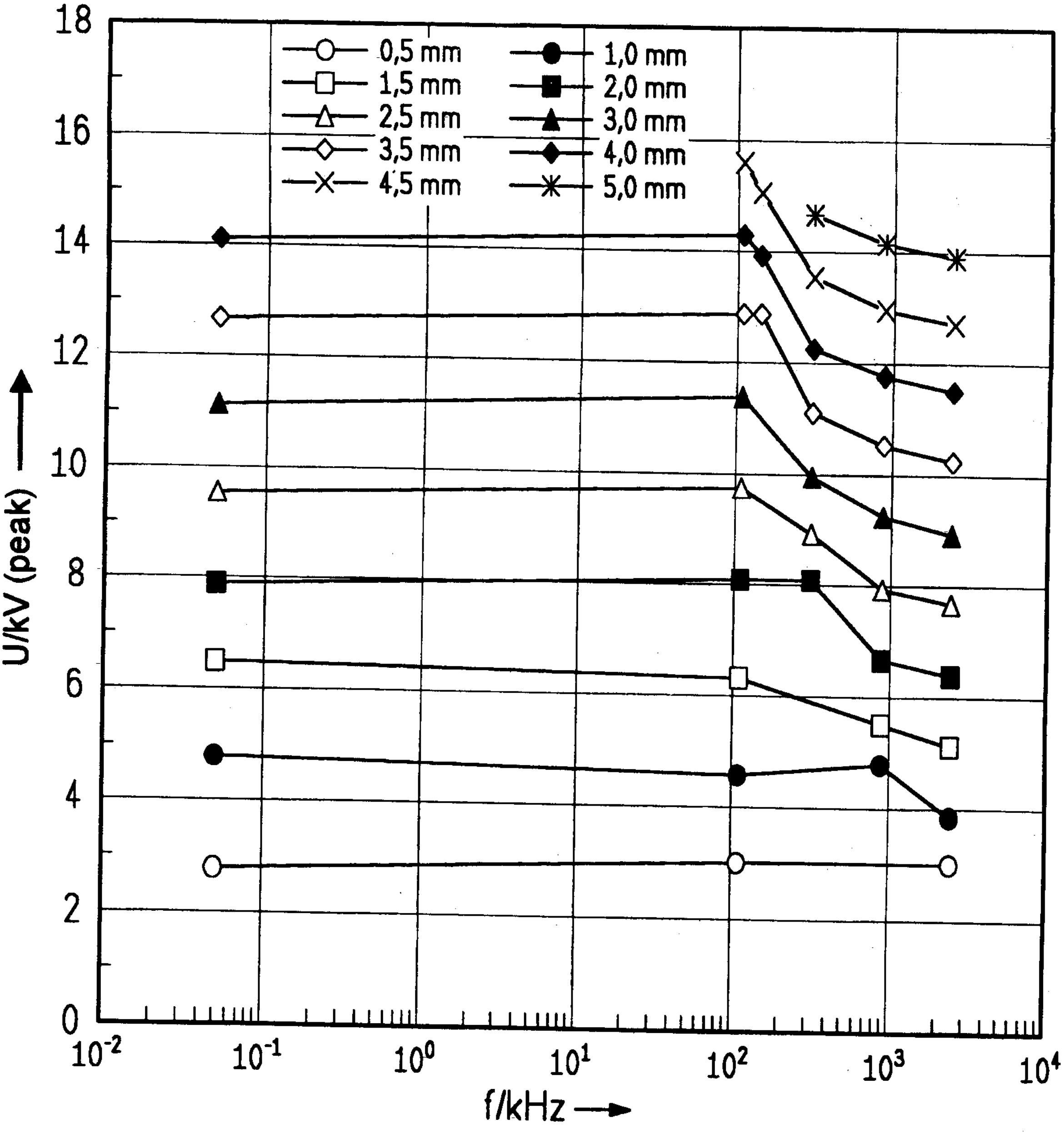


Figure 4 – Breakdown at high frequency in air, homogeneous field [4]

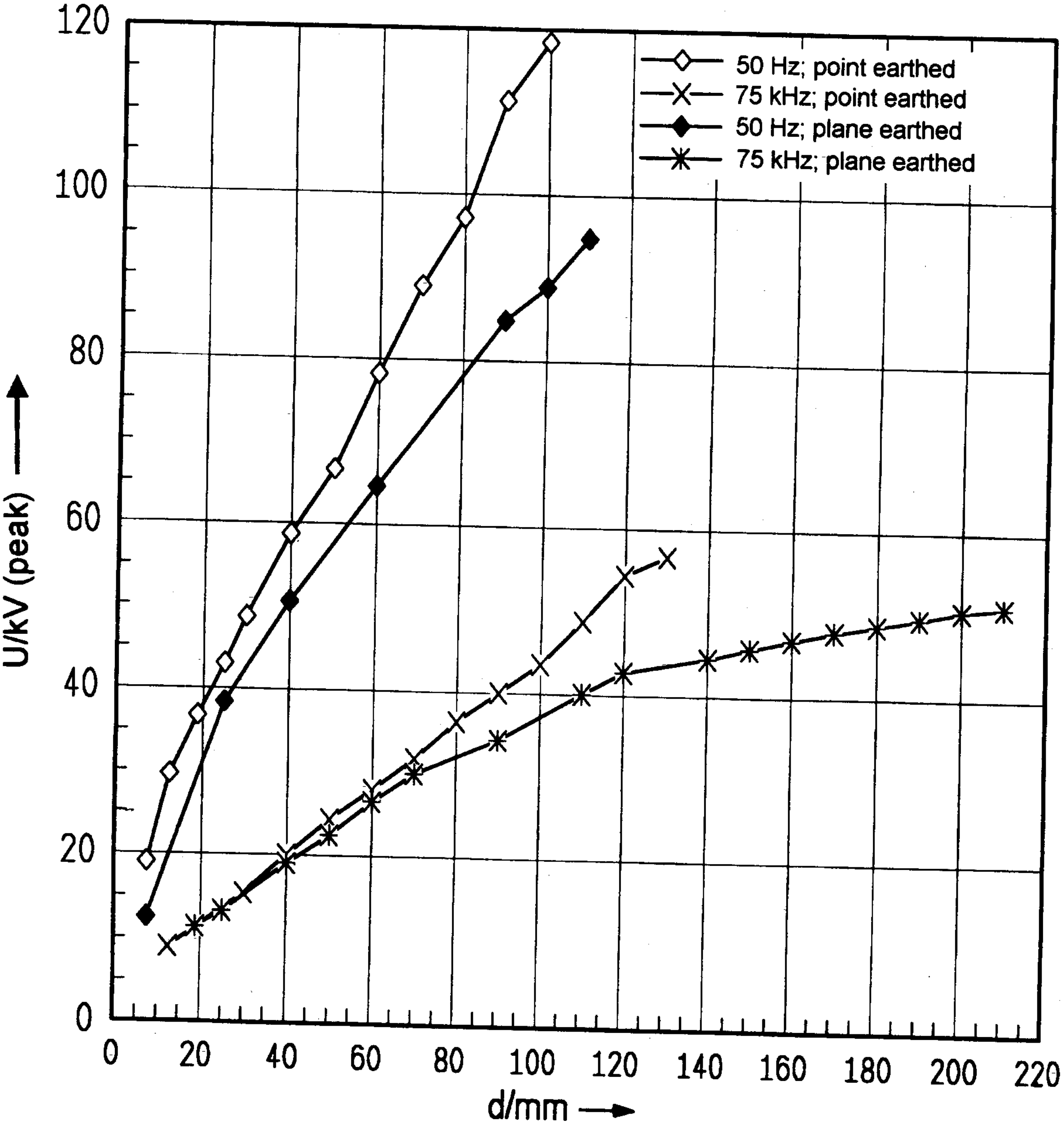
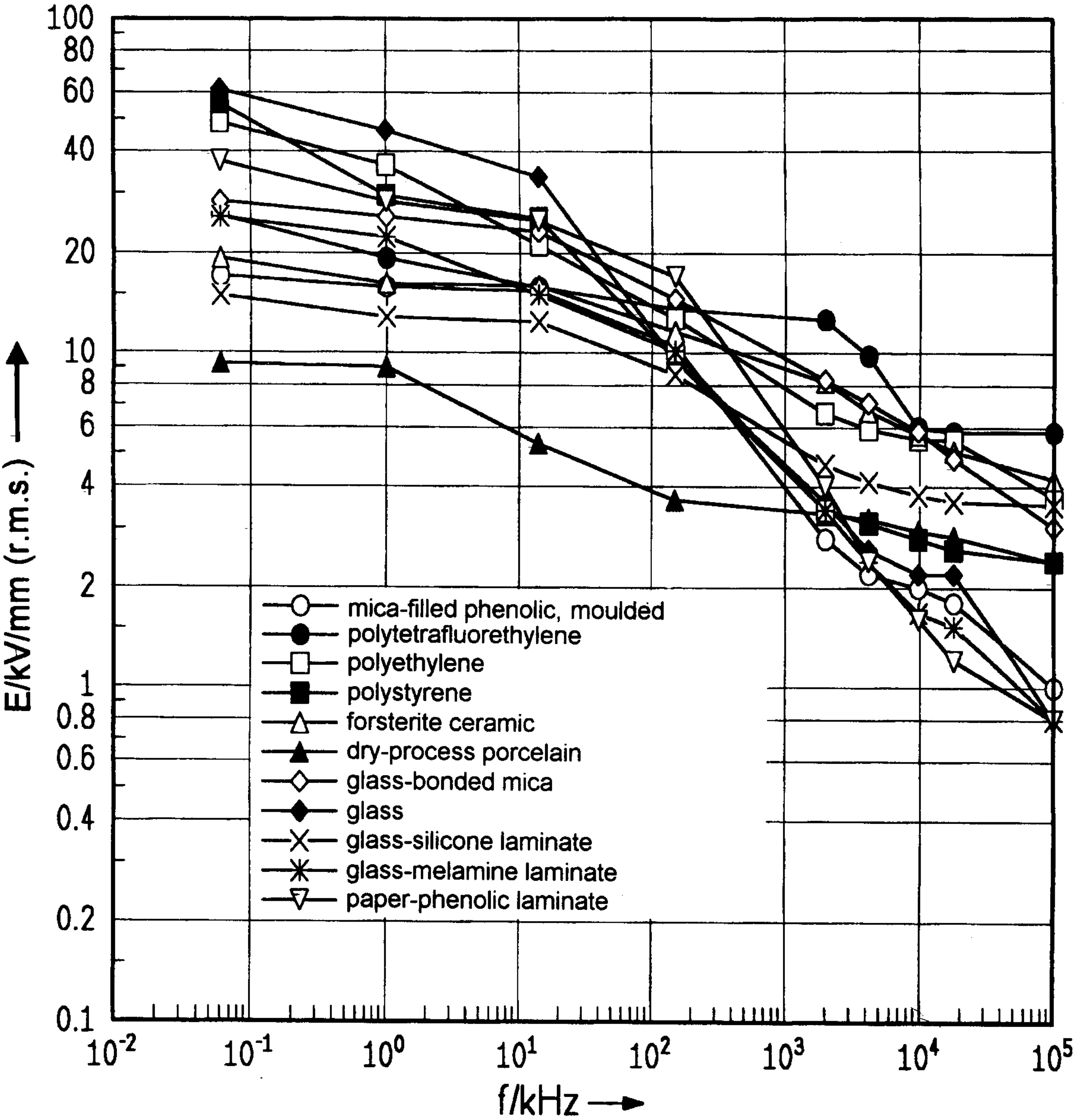


Figure 5 – Breakdown at high frequency in air, inhomogeneous field [5]



d = 0,75 mm

Figure 6 – Breakdown at high frequency, solid insulation [8]

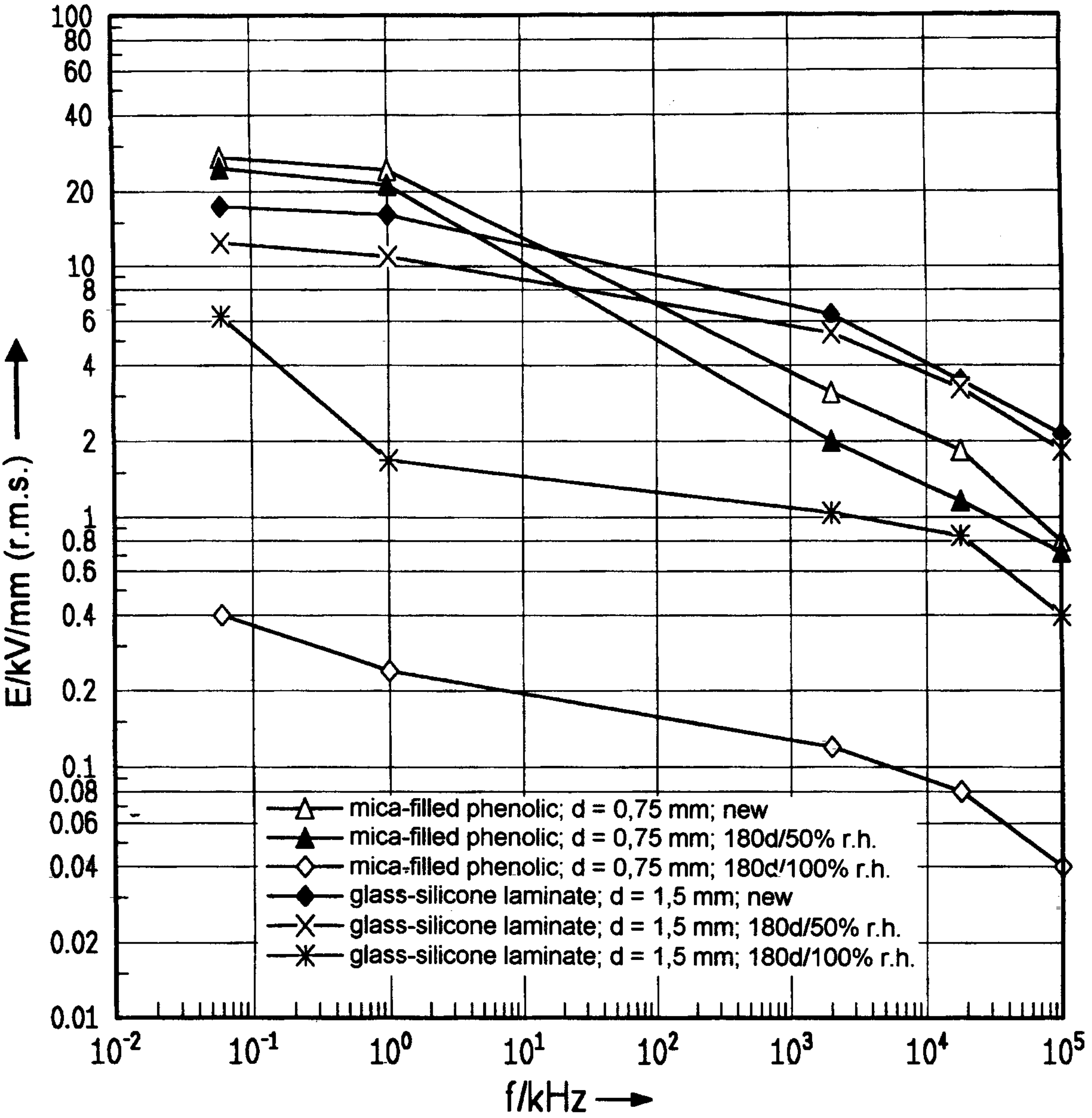


Figure 7 – Breakdown at high frequency, solid insulation; conditioning at 50 °C [9]

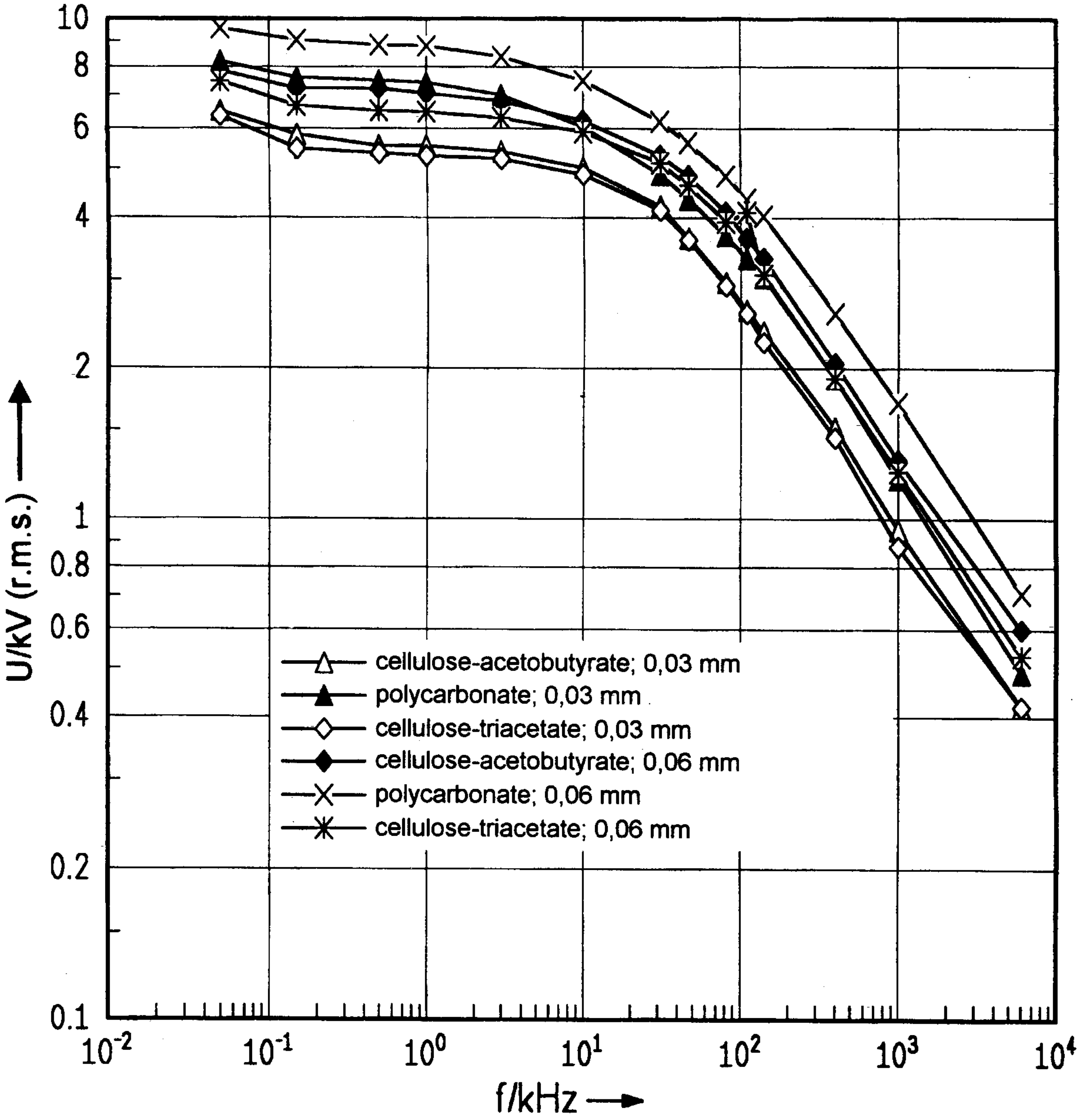


Figure 8 – Breakdown at high frequency, insulating films [10]

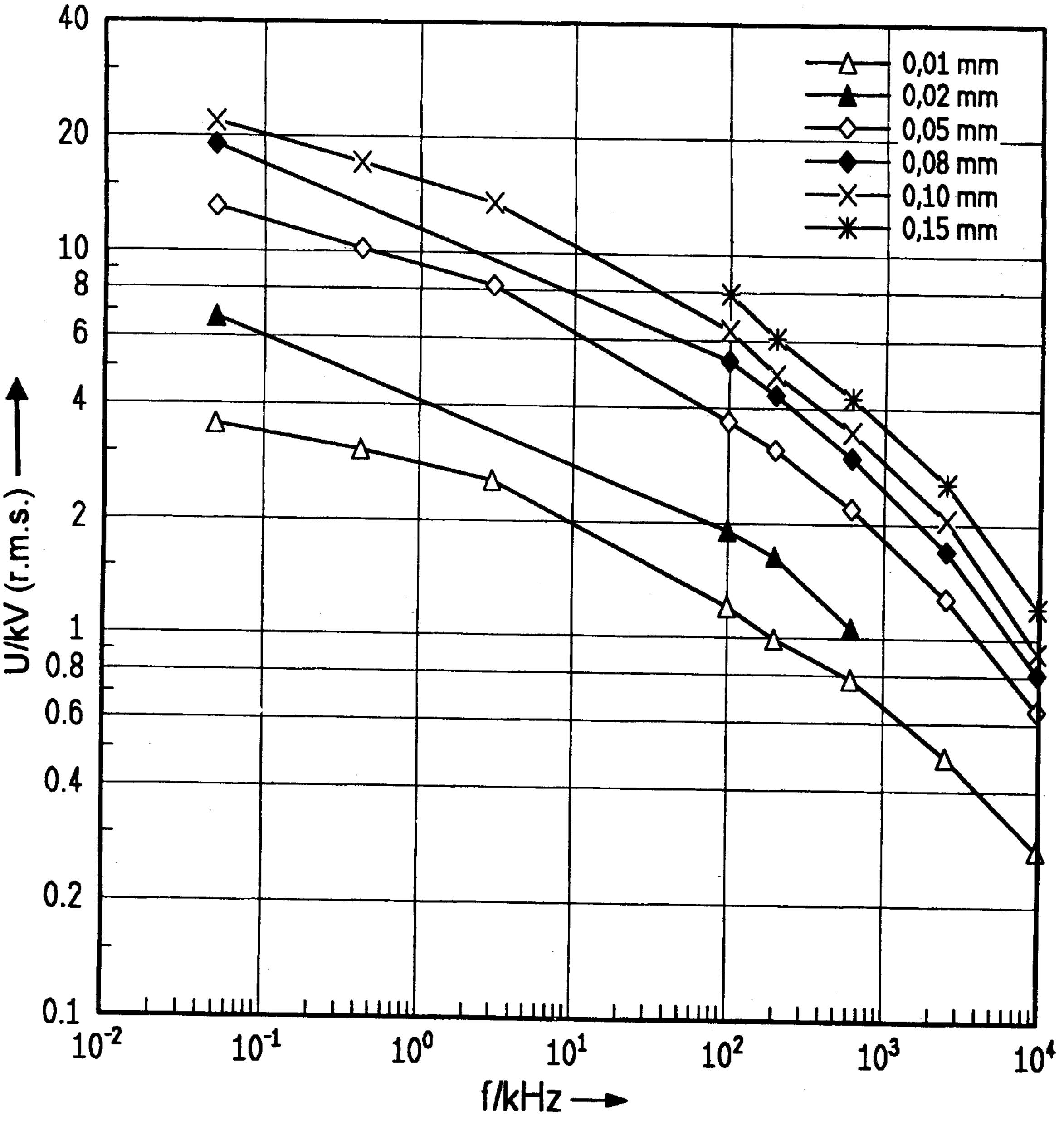


Figure 9 – Breakdown at high frequency, polystyrene film at 20 °C [10]

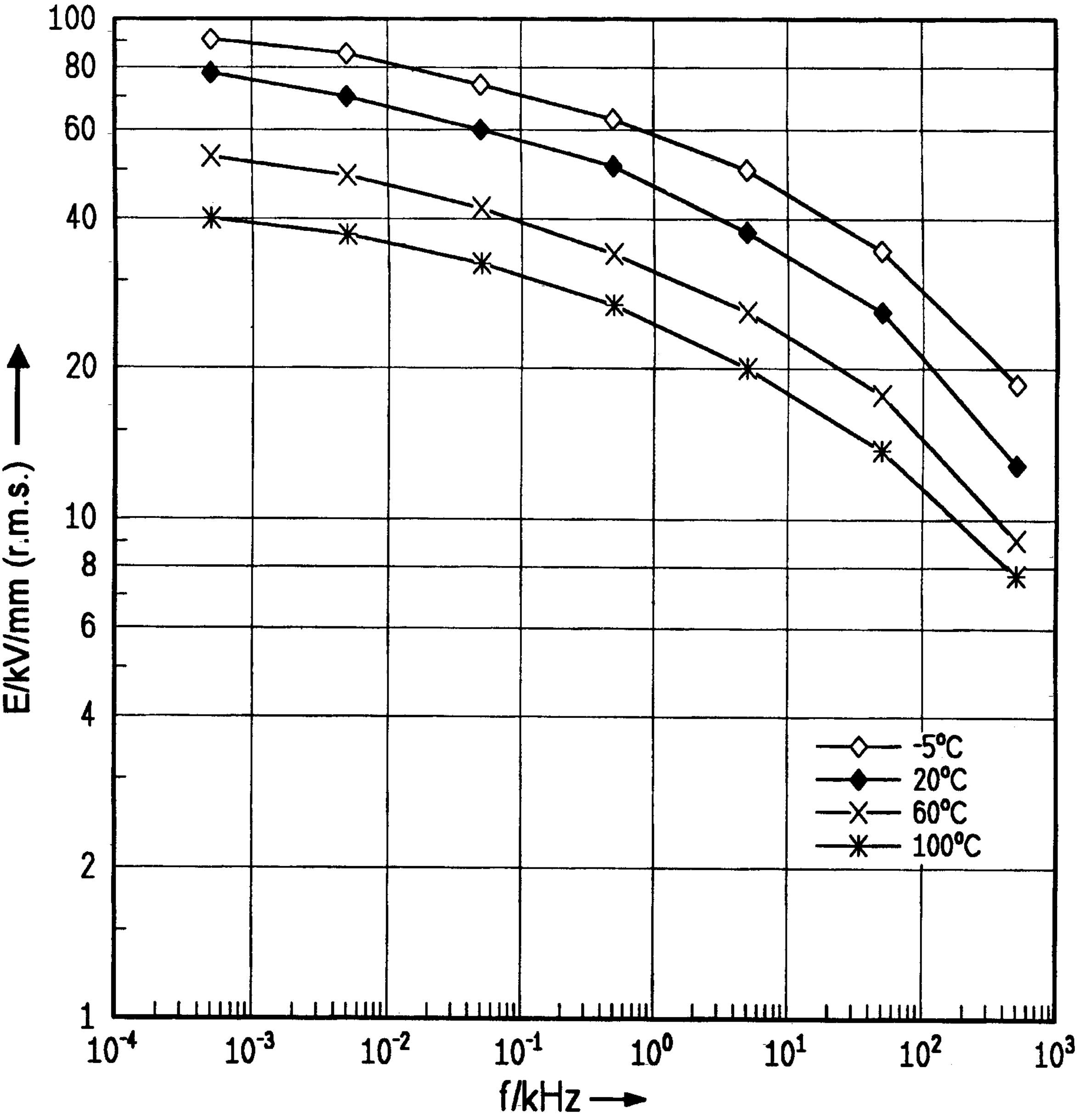


Figure 10 – Breakdown at high frequency, paper laminate (pertinax); temperature [11]

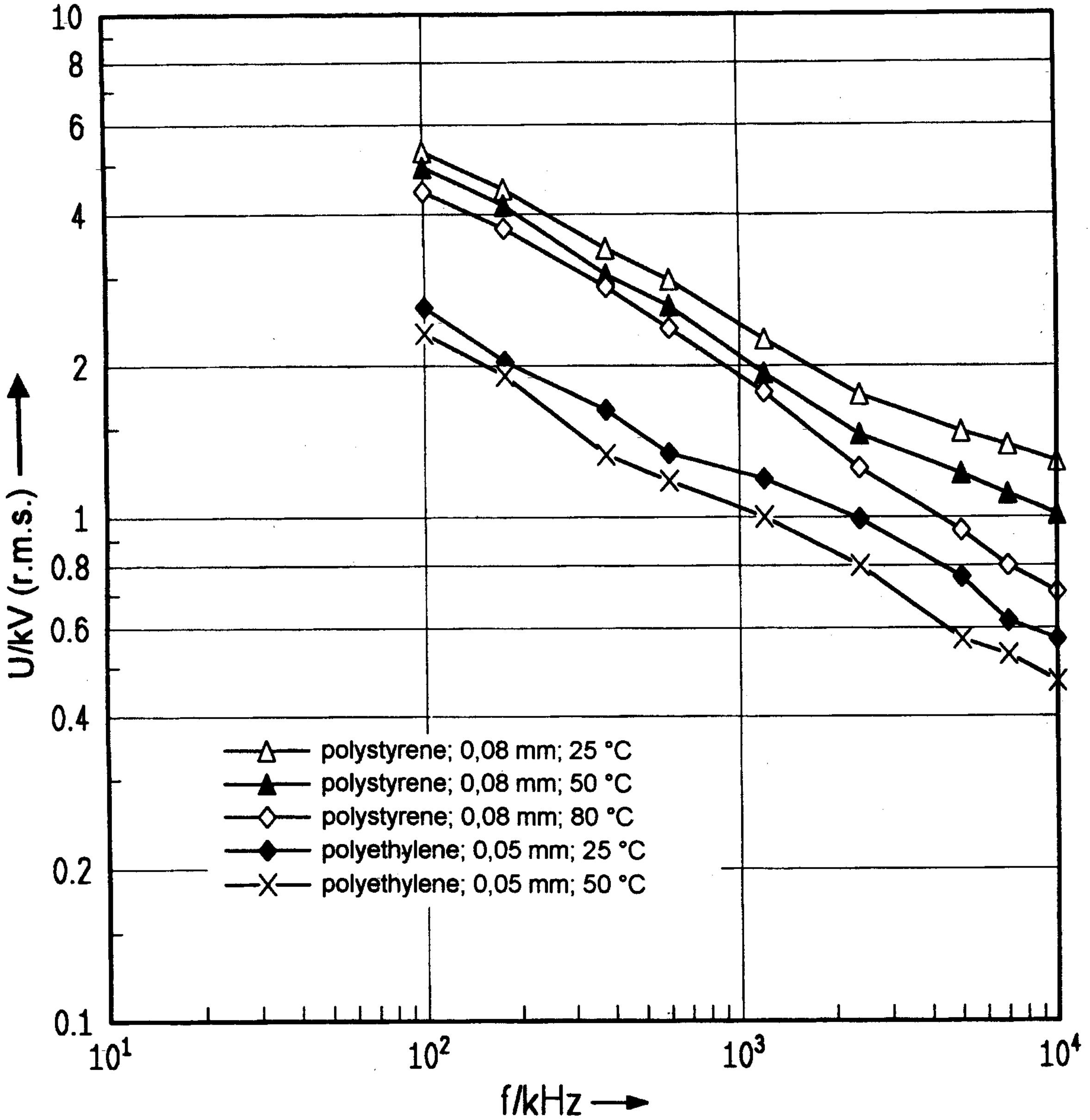
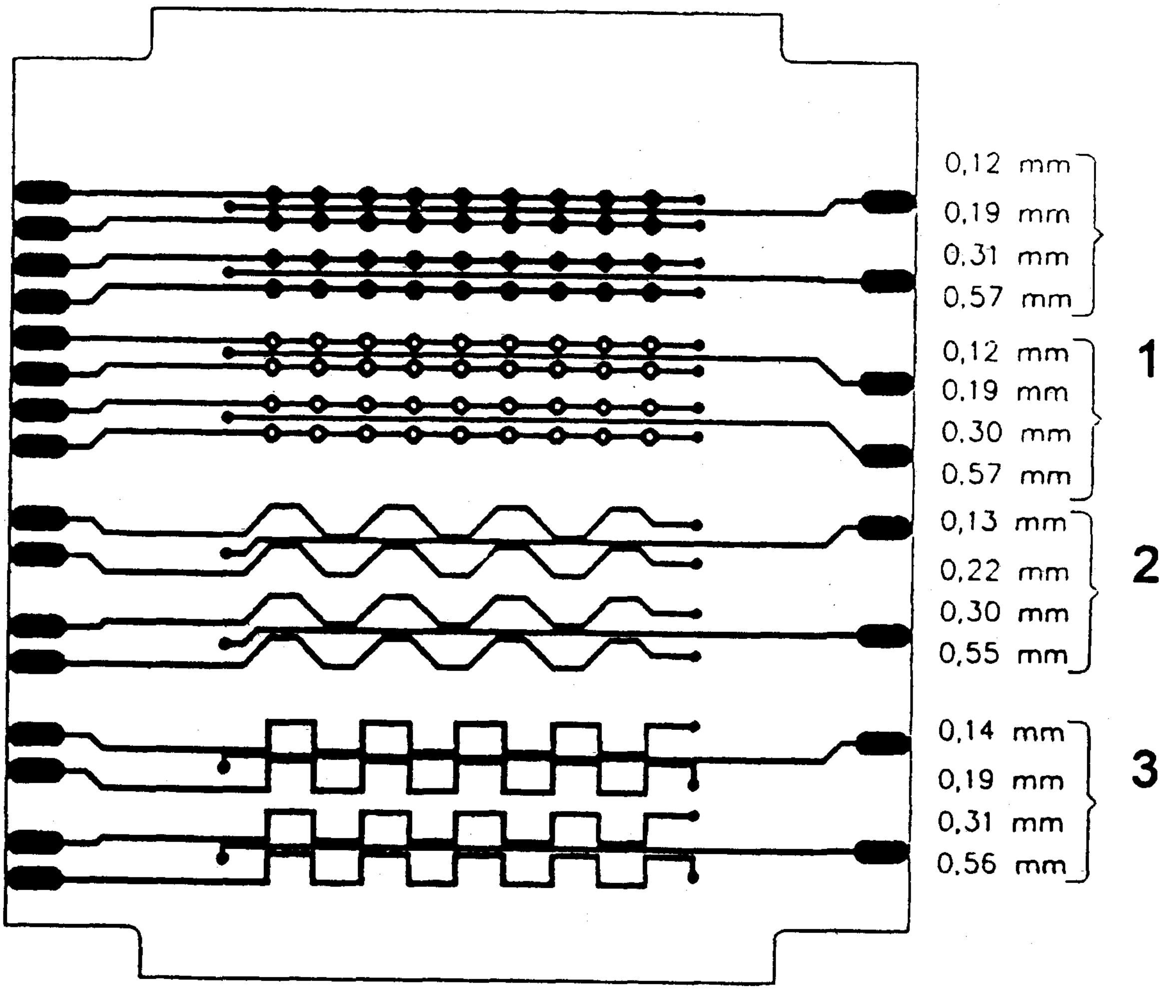


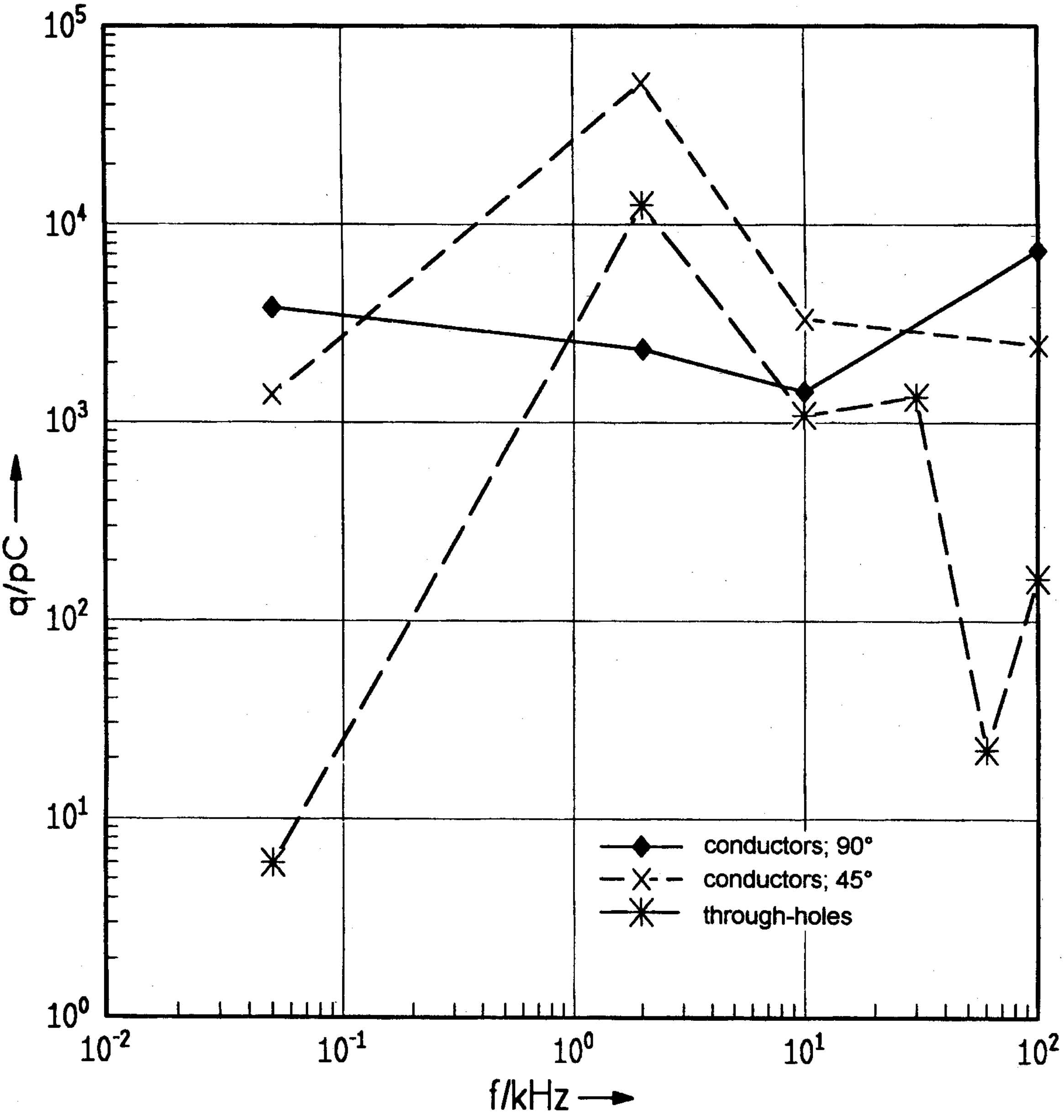
Figure 11 – Breakdown at high frequency, insulating films; temperature [10]



1 – through holes (interconnecting of layers)
2 – conductors 45°
3 – conductors 90°

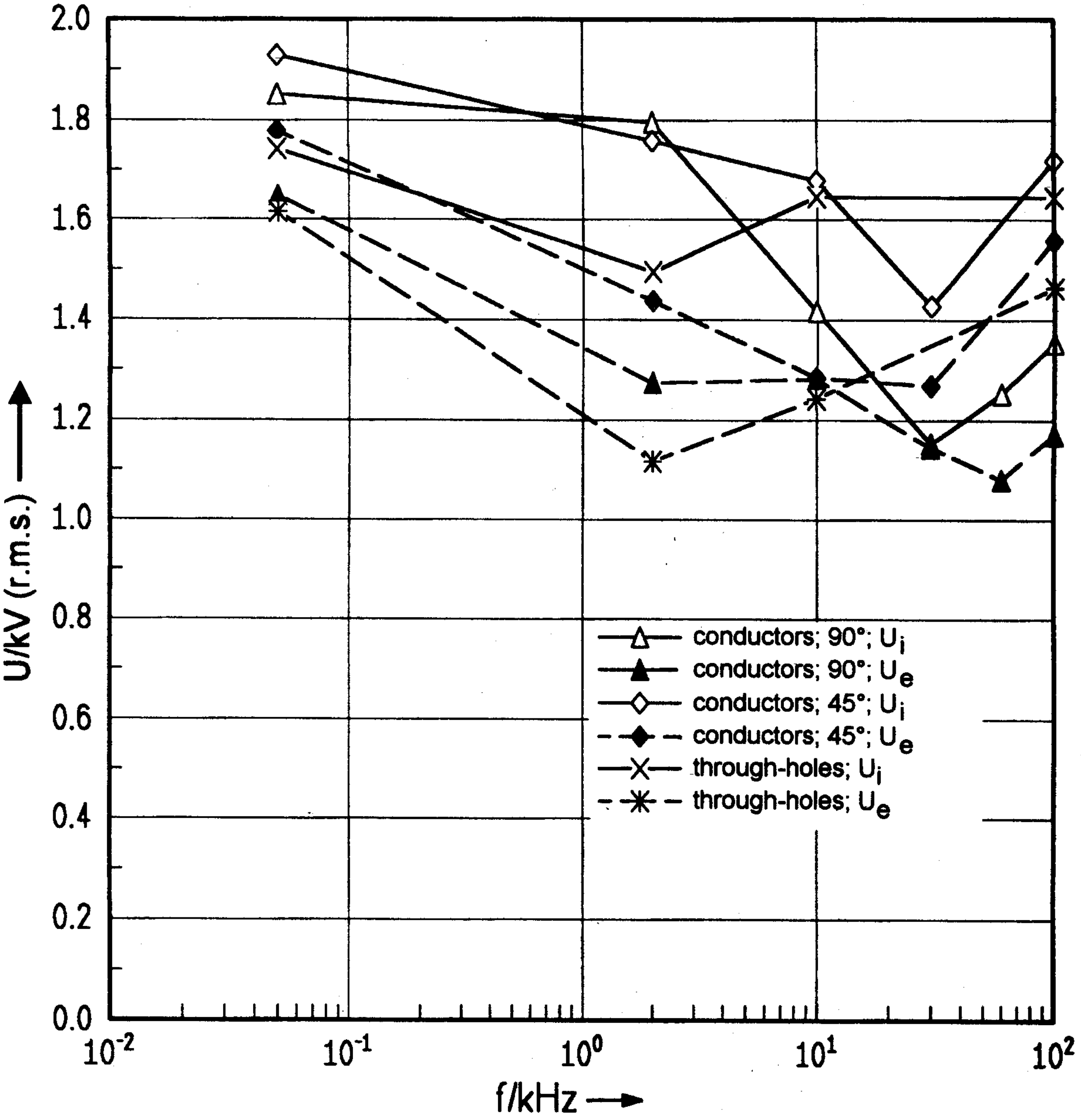
The distance values are the smallest ones between adjacent conductors actually being measured.

Figure 12 – Layout of the test board



d = 0,3 mm

Figure 13 – Partial discharge at high frequency, coated printed circuit board [15]



d = 0,2 mm

Figure 14 – Partial discharge at high frequency, coated printed circuit board [15]

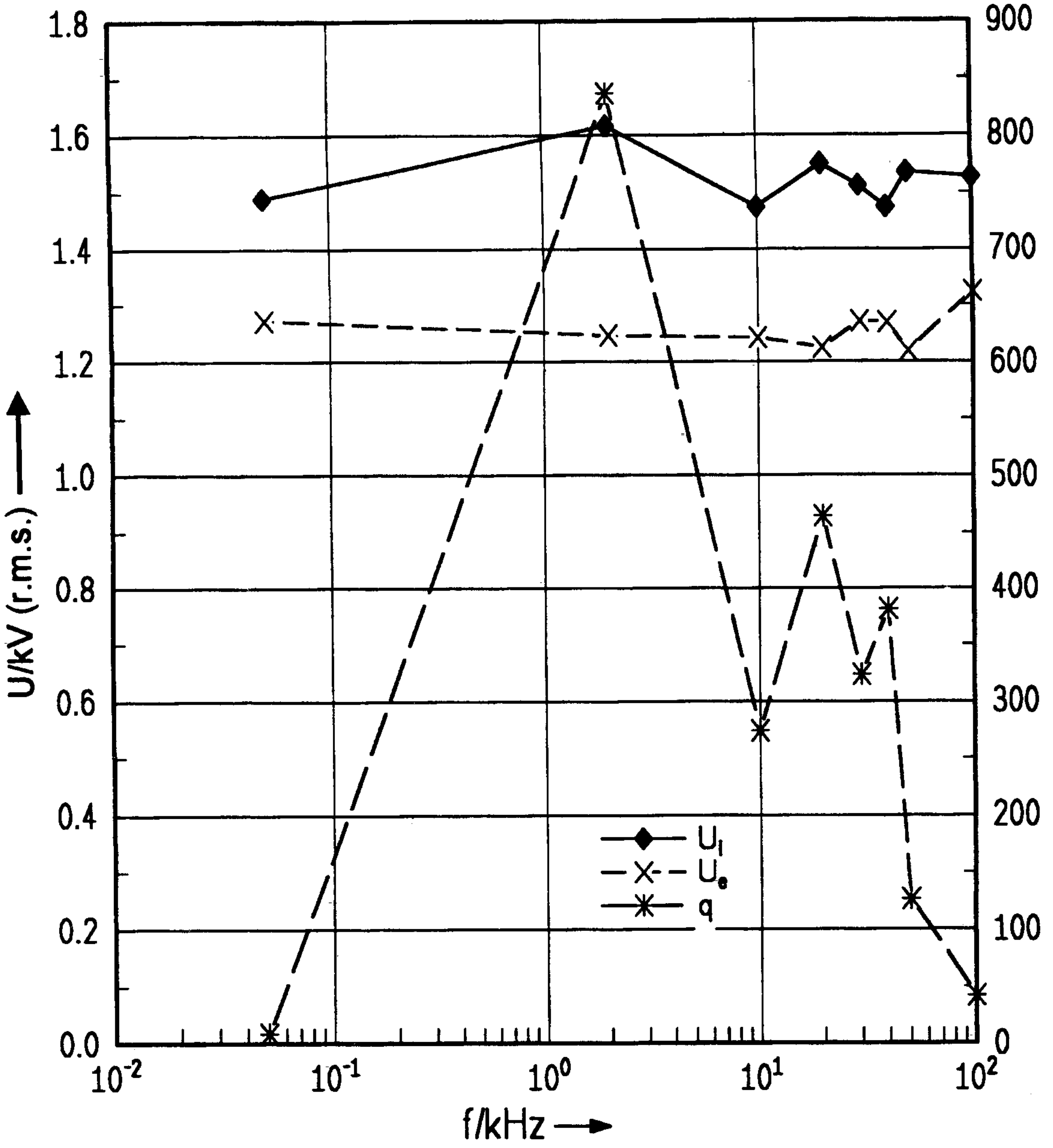


Figure 15 – Partial discharge at high frequency, optocoupler [15]

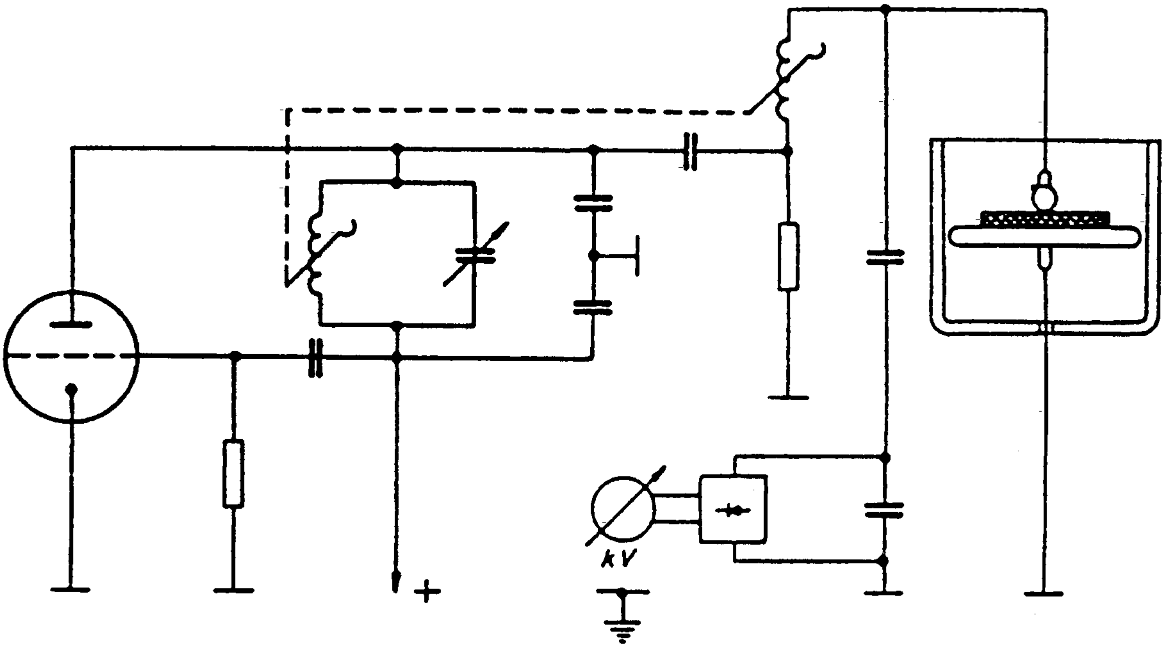
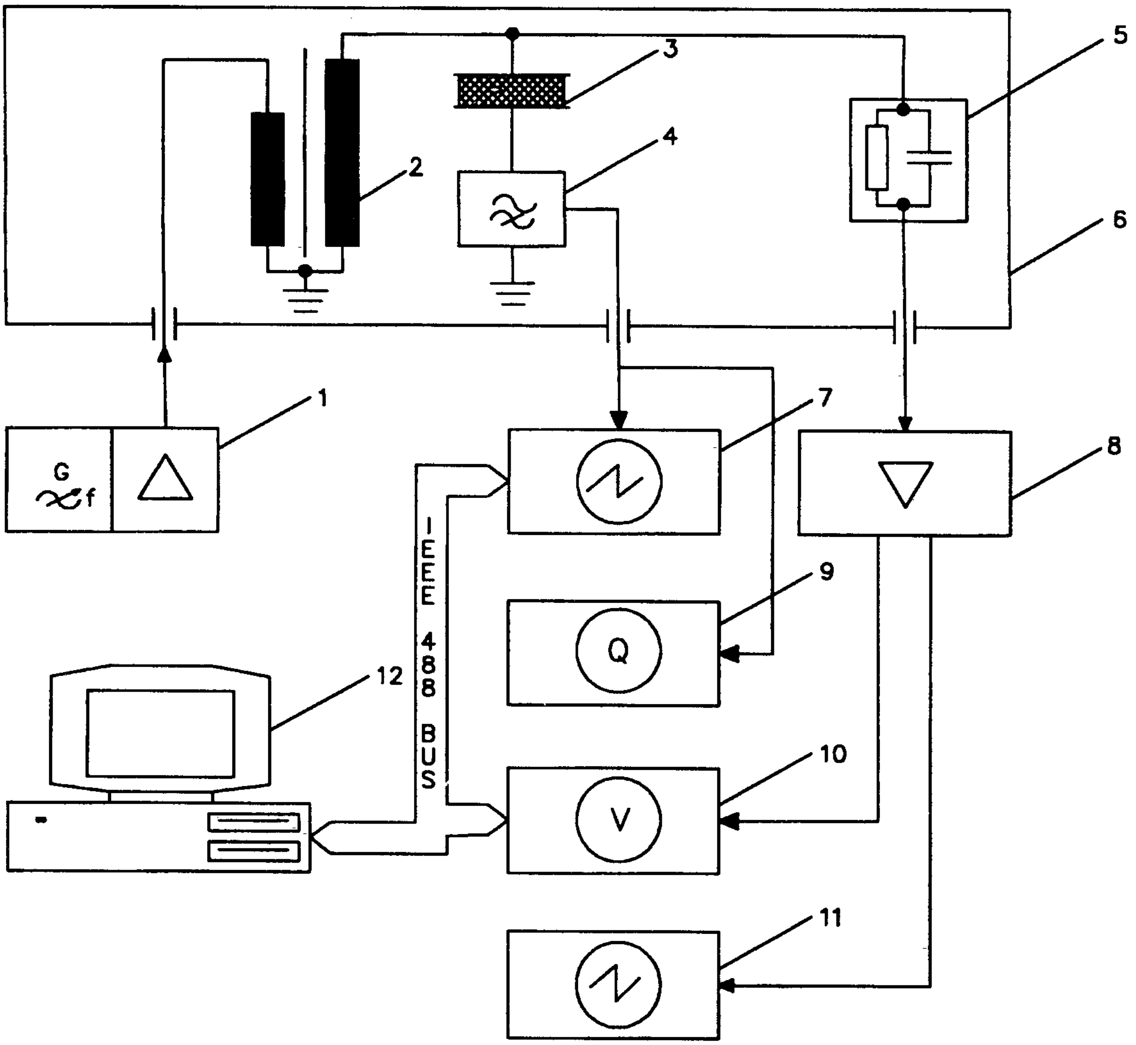
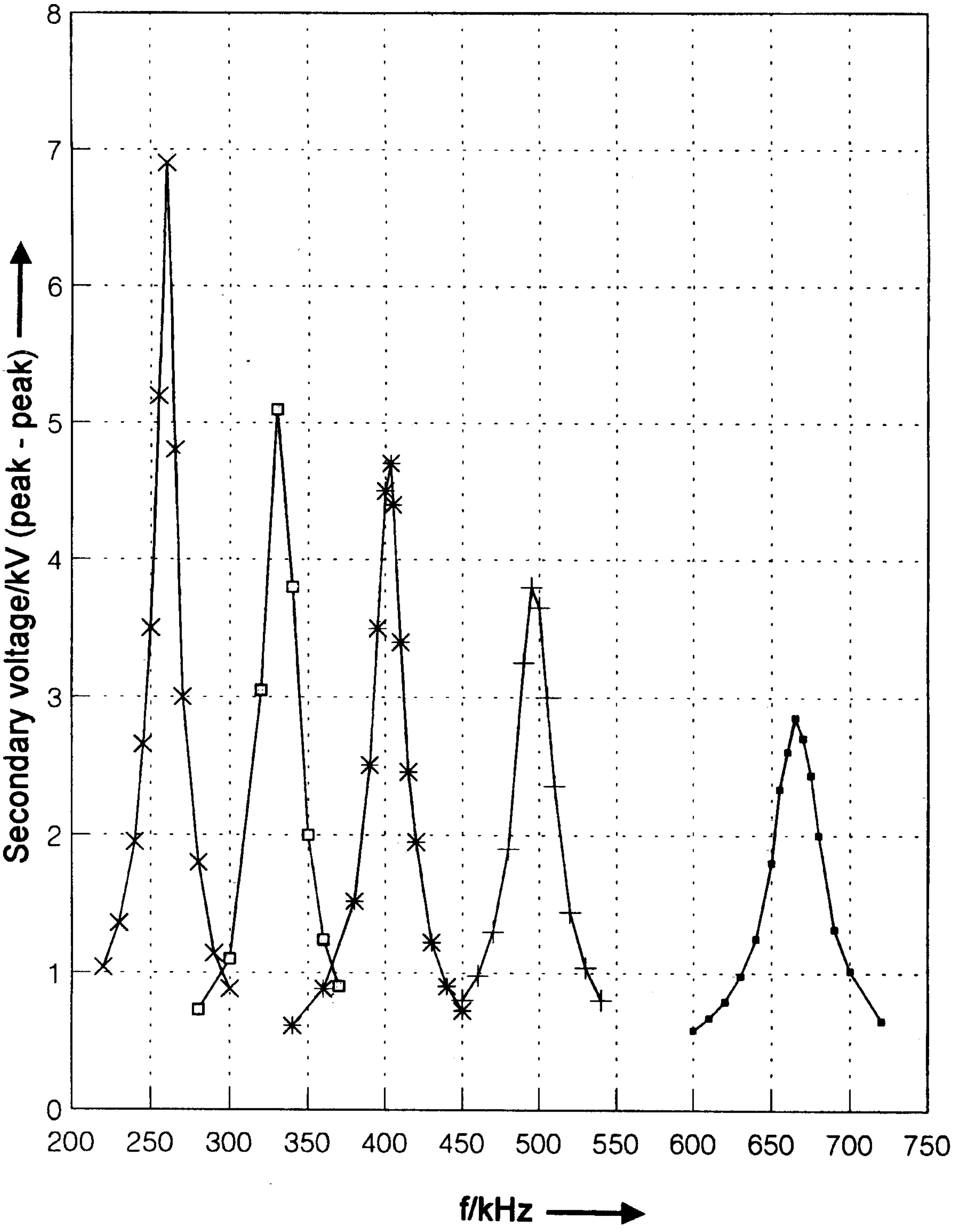


Figure 16 – Basic circuit of a HF power oscillator (colpitt circuit)



1 – HF generator and power amplifier, *f* = 2 kHz – 500 kHz
2 – HF resonance transformer
3 – test specimen
4 – coupling impedance
5 – HF high-voltage probe
6 – screened cage
7 – digital storage oscilloscope
8 – impulse amplifier
9 – conventional partial discharge detector
10 – digital voltmeter
11 – analogue oscilloscope
12 – control computer

Figure 17 – HF partial discharge test circuit



Number of primary turns N_1 = 20;

Number of secondary turns N_2: ■ – 210, + – 280, ✳ – 350, □ – 420, × – 560

Figure 18 – Output voltage of HF resonance transformers

Annex A

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For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding of numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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Amendments Issued Since Publication

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